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Optical Properties of Cirrus Derived from Airborne Measurements During FIRE IFO II

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1. Introduction

The Radiation Measurement System (RAMS) on board the NASA ER–2 was used to acquire several optical parameters of interest during the FIRE Cirrus IFO II. In this abstract we present results from the November 26 IFO when the ER–2 flew over the Coffeyville airport hub site. We show retrieved optical thickness and cloud temperature, along with optical thickness obtained from RAMS instruments on the NCAR Sabreliner and at the surface site B. Independent retrieval of optical thickness, from the ER–2 and at the surface, are in agreement during the overpasses. Cirrus optical depths, derived from each platform, ranged between 1 and 2.

2. Instrumentation

RAMS was comprised of several broad and narrow–band, hemispheric and narrow–field–of–view, solar, near–infrared, and thermal infrared radiometric sensors during the FIRE IFO II. The following instruments were used to acquire the data described in this paper. Another paper will discuss the comparison of model calculations with measured broadband flux.

a) Narrow–Field–of–View IR Radiometer (NFOV): The NFOV is a dual channel infrared radiance measuring device, using a liquid nitrogen cooled blackbody reference. The two channels have 1 μm bandwidths, with band–centers at 6.7 μm and 10.5 μm. The NFOV was mounted off to the side of the ER–2 fuselage and was nadir–looking. Another NFOV was deployed at the Coffeyville airport hub, site B.

b) Total–Direct–Diffuse Radiometer (TDDR): The TDDR is a seven channel visible and near–infrared radiometer with a rotating shadow band capable of separating the direct and diffuse components of the solar flux. The bandwidths are narrow (10 nm) and are located outside atmospheric absorption bands, isolating the optical effects due to aerosol. The TDDR was pointed in the zenith direction on the ER–2, and Sabreliner, and at the surface in Coffeyville.

3. Optical Thickness and Temperature

Cirrus optical depth was measured from three platforms: ER–2, using the 2–channel infrared NFOV; Sabreliner, using the 7–channel visible and near–infrared TDDR; and surface (site B at the Coffeyville airport), also using the TDDR.

a) ER–2

The 6.7 and 10.5 μm NFOV channels are used to determine remotely cirrus visible (0.55 μm) optical thickness and cloud temperature, following the method described in Liou, et al.(1990). Clear–sky radiance at cloud base must first be determined, and fortunately, for the November 26 case study, the ER–2 was on site over Kansas before cirrus had moved in. The Planck black body radiance at both wavelengths is computed using Newton's iteration, from which cloud temperature is determined. The cloud emmissivity is found from the ratio (at either wavelength, since ϵ is only very weakly dependent on λ) of the cloud–top upwelling radiance to the blackbody radiance. Cirrus optical thickness,

τ, then, is found using the parameterization

$$\epsilon=1-\exp(a\tau^{b}),$$

where a is −0.468 and b is 0.988.

b) Sabreliner

Using the TDDR on the Sabreliner affords the advantage that an absolute calibration is unnecessary, and the derived optical thickness pertains to shallow layers, eliminating both Rayleigh extinction and extinction due to aerosols between cloud top and the top of the atmosphere. The TDDR separates the direct and diffuse components of the downwelling flux at each Sabreliner flight level. Direct flux at one level (in arbitrary units) is related to that at any other level through Beer's Law, determining the layer extinction.

c) Surface

The surface TDDR measurement also separates direct and diffuse flux but unlike the Sabreliner measurements, direct flux must be compared to exoatmospheric values derived from independent calibrations. Resultant optical thickness refers to the entire column above the detector. Rayleigh extinction is simply removed; to isolate cirrus optical depth, however, clear–sky measurements are used to determine aerosol extinction.

On November 26, between 1730 and 2000 GMT, the ER–2 flew nearly east–west racetracks with the western pivot point over Coffeyville (figure 1). In figure 2, the ER–2 NFOV retrieved cloud optical depth is shown as a function of time, along with the simultaneous ground–based measured optical depth. Keep in mind that the data includes the entire ER–2 racetrack, only a small portion of which is over Coffeyville. Furthermore, the surface–derived TDDR optical thickness pertains to that section of cloud toward the solar direction, not the zenith point where the ER–2 retrievals were made. Small arrows indicate when the ER–2 was nearly overhead at Coffeyville. At those times, agreement between the two datasets (and independent retrieval methods) is outstanding. Furthermore, the same general trend appears in both data sets, i.e., the gradual increase in cloud thickness as time progresses.

Figure 3 shows the ER–2 retrieved cloud temperature, together with the 6.7 μm and 10.5 μm brightness temperature. All three curves converge as the cloud becomes thicker (blacker). In figure 4, the background stratospheric aerosol optical depth is plotted as a function of wavelength. This spectrum was compiled from averages of spectra acquired from the ER–2 TDDR during the racetracks. Note that these relatively high levels of "background" extinction indicate the strong influence of the Pinatubo volcanic cloud at that time.

Optical depths from the Sabreliner are shown in figure 5. The Sabreliner flew twice during the November 26 IFO, in the morning (local time) and afternoon. We felt it more appropriate to show the morning flight data here for the following reasons: Although this flight occurred prior to the ER–2 overflight, it was in an region northwest of Coffeyville, the same direction from which the cirrus deck later approached. The afternoon flight, while directly above the hub site, occurred as the largest mass of highest cirrus was moving to the east. Consequently, the afternoon flight legs between 7 and 9 km show very thin cirrus, not directly comparable to that shown in figure 2.

4. Conclusions

Broad intercomparison between the multiple–platform derived optical depths for the November 26 IFO shows the general features of the cloud structure over southeastern Kansas. Several overpasses of the ER–2 at Coffeyville allow for comparison of two independent methods of determining cirrus optical depth; results show outstanding agreement between the 2–channel infrared method and the TDDR derived optical thickness. Comparison of results with in situ microphysical measurements, in particular the Sabreliner derived vertical profiles of optical depth, will be vital to relating the derived optical properties to various broadband radiation measurements.

5. Reference

Liou, KN, SC Ou, Y Takano, FPJ Valero, and TP Ackerman, *J. Appl. Meteor.*, 29, 716–726, 1990.

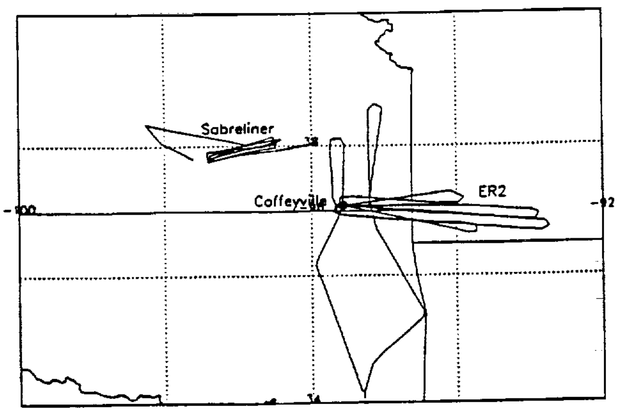


Figure 1. ER–2 Sabreliner (am) flight tracks on November 26, 1991.

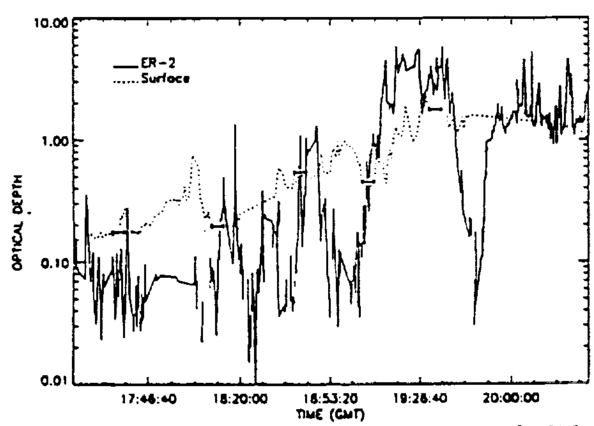
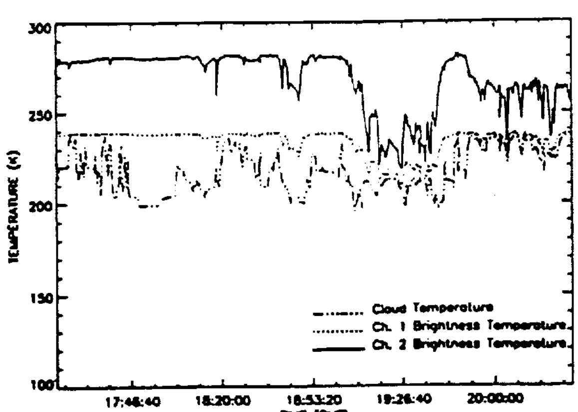


Figure 2. ER–2 2–channel IR retrieval (solid curve) and surface TDDR measurement (dotted) of mid–visible (0.5 μm) optical depth.



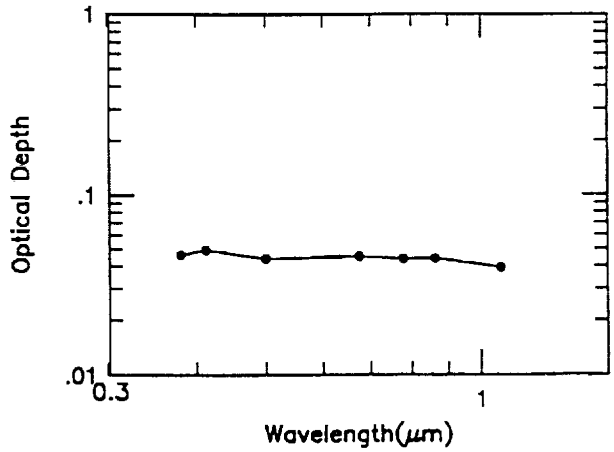


Figure 4. Stratospheric aerosol extinction measured from the ER–2 (TDDR).

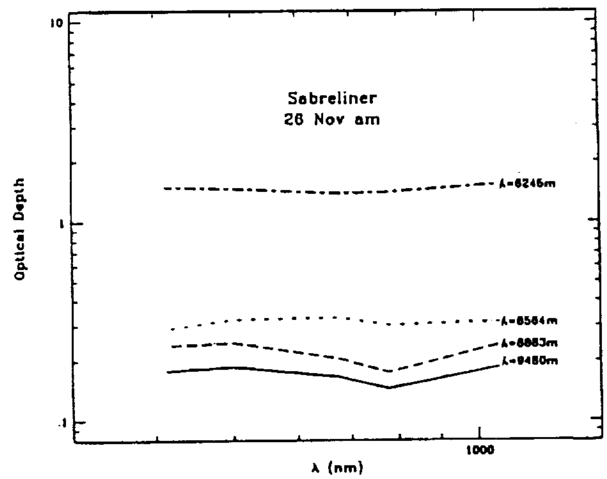


Figure 5. Sabreliner TDDR measurements of cirrus optical thickness. Leg altitudes are indicated on the right.

←Figure 3. 6.7 μm (dotted curve) and 10.5 μm (solid) cloud brightness temperature, with retrieved cloud temperature (dot–dash).